STUDY OF OSL AND TL RESPONSE OF $CaSO_4$:Dy, LiF:Mg,Ti AND MICROLiF:Mg,Ti DOSIMETERS TO BETA AND GAMMA RADIATION

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Abstract
The Optically Stimulated Luminescence (OSL) is a signal emitted by an insulating or semiconducting material when exposed to light, after being irradiated. The intensity of the OSL signal is proportional to radiation dose absorbed by the detector. The process is similar to the thermoluminescence, but differs in the stimulation: instead of thermal stimulation, in OSL defects in the detector are stimulated by optical means. The use of OSL is growing and OSL dosimeters have recently been studied and investigated for medical dosimetry applications. These dosimeters share many properties of interest for this application. This paper aimed to study and compare the OSL and TL dose-response, the repeatability and the sensitivity of the $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to beta and gamma radiation and evaluate its possible application in arc-IMRT (VMAT) dosimetry.

Keywords: lithium fluoride, thermoluminescence, optically stimulated luminescence, dosimetry, beta radiation.

1. INTRODUCTION

Thermoluminescence (TL) is a process of stimulating, using thermal energy, the emission of luminescence from a substance following the absorption of energy from an external source by that substance. Optically stimulated luminescence (OSL) is a similar process than TL but, the luminescence is stimulated by the absorption of optical energy, rather than thermal energy [Yukihara and McKeever, 2011].

The dosimetry of ionizing radiation is essential for the radiological protection programs for quality assurance and licensing of equipment. In radiotherapy treatments is necessary to be sure that the patient is receiving the correct prescribed dose and the main objective of dosimetry in radiotherapy is to determinate with greater precision the absorbed dose to the tumor [Metcalfe, Kron and Hoban, 2007].

In radiotherapy treatments is necessary to be sure that the patient is receiving the correct dose prescribed. The main objective of radiotherapy dosimetry is to determine with great precision the dose absorbed to the tumor. The clinical dosimetry main objectives are to promote the radiation protection of individuals (patients and staff) and establish a radiation beam quality control [Oberhofer e Scharmann, 1979]. The high energy electron beams have broad application in medicine, especially in the treatment of various cancers. Several organizations recommended the verification of patient dose for quality improvement in radiotherapy and the International Committee of Radiation Units and Measurements (ICRU) establish, in 1976, that "*all procedures involved in planning and execution of radiotherapy may contribute to a significant uncertainty in the dose administered to the patient".* The recommended maximum values for the uncertainty in the dose range of ± 5% [ICRU, 1976].

The conventional IMRT and arch-IMRT (VMAT) are new techniques responsible for a change in the setting of radiotherapy, bringing benefits and allowing a lower toxicity in the treatment of patients. With these treatment modalities is possible to minimize the radiation dose to the healthy tissues and escalate the dose to the target volume (tumor) [Hall, 1998; Mundt, 2005; Bortfeld, 2006]. Until recently, few methods of quality control are well established techniques for IMRT. To guarantee that the IMRT services accord the highest clinical standards, each institution should invest in a quality control program for treatment planning and dose absorbed [Palta et al, 2008]. As the deployment of equipment arc-IMRT is still at the beginning is important to optimize and facilitate quality control mechanisms to ensure that tests are performed in order to preserve above all the patient but also the equipment itself [Hancock, 2008].

The TLDs have a long history of ionizing radiation dosimetry and most measurements have been done with lithium fluoride doped with magnesium and titanium (LiF:Mg,Ti). It was perhaps the earliest material to be used in TL dosimetry following its development at the University of Winsconsin in the 1950s [Oster, Horowitz and Podpalov, 2010]. TLDs are popular dosimeters in many hospitals for external dosimetry during radiotherapy treatment, however, the TLD can only provide an integral reading of the total surface exposure to the patient after treatment. On the other hand, OSL has the potential for the development of near-real-time dosimetry in wich the measured quantity can be either dose or dose rate [Bøtter-Jensen, McKeever and Wintle, 2003].

The use of OSL in medical dosimetry is growing. Properties as high sensitivity and the all-optical nature of the process are the two properties exploited most in medical dosimetry application. [Yukihara and McKeever, 2011]. The OSL response of LiF:Mg,Ti (TLD-100) dosimeters to alpha and beta particles to application to mixed-field radiation dosimetry was investigated by Oster et al by measuring the excitation and emission spectra of OSL and comparing with thermoluminescent (TL) characteristics [Oster, Horowitz and Podpalov, 2010].

This paper aimed to study and compare the OSL and TL dose-response, the repeatability and the sensitivity of the $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to beta and gamma radiation and evaluate its possible application in arc-IMRT (VMAT) dosimetry.

2. MATERIALS AND METHODS

2.1 MATERIALS AND EQUIPMENTS

- ✓ 25 $CaSO_4$:Dy dosimeters;
- ✓ 25 LiF:Mg,Ti dosimeters;
- ✓ 25 LiF:Mg,Ti microdosimeters;
- ✓ ^{60}Co gamma source (656.4MBq);
- ✓ ^{90}Sr/^{90}Y beta source (1.48 GBq);
- ✓ Furnace VULCAN model 3-550 PD;
- ✓ Furnace FANEN model 315-IEA 11200;
- ✓ TL/OSL Risø reader model TL/OSL-DA-20;
- ✓ Blue Led NICHIA - NSPB-500AS (470 nm);
- ✓ Hoya U-340 filter (7.5 mm thick, ø = 45 mm).

2.2 METHODS

Before irradiations the $CaSO_4$:Dy dosimeters were heat-treated 300ºC/3h and LiF:Mg,Ti and microLiF:Mg,Ti dosimeters 400ºC/1h + 100ºC/2h using the furnaces VULCAN model 3-550 PD and FANEN model 315-IEA 11200 respectively. To select the dosimeters according to their TL and OSL sensitivity all dosimeters of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti were irradiated in air under electronic equilibrium conditions with a ^{60}Co gamma source.

After the readings the individual and average TL and OSL responses of the dosimeters were obtained and they were separated into 15 groups of 5 detectors each according to their TL sensitivity (5 groups of $CaSO_4$:Dy, 5 groups of LiF:Mg,Ti dosimeters and 5 groups of LiF:Mg,Ti microdosimeters).

The beta irradiations were done using ^{90}Sr/^{90}Y source inserted into the TL/OSL Risø reader model TL/OSL-DA-20 of the Gerência de Metrologia das Radiações (GMR-IPEN/CNEN) and the gamma irradiations were done using a ^{60}Co source of the Centro de Tecnologia das Radiações (CTR-IPEN/CNEN), with doses ranging from 0.1 up to 10 Gy. The TL and OSL readings were performed using the same equipment TL/OSL Risø reader model TL/OSL-DA-20

To the TL and OSL readings the dosimeters were loaded onto an exchangeable sample carousel that can accommodate up to 48 samples. In the measurement position the sample can be stimulated thermally or optically. Thermal stimulation is obtained by linearly increasing the temperature of the heating element and optical stimulation is provided by different light sources focused onto the sample position. To OSL measurement of the dosimeters were stimulated with Blue Led NICHIA - NSPB-500AS (470 nm) to OSL signal readings and for this measurement was used the Hoya U-340 filter.

The dose-response curves were obtained to the following doses: 0.1, 0.5, 2.0, 5.0 and 10 Gy. Each presented value is the average of five measurements of dosimeters of the same sensitivity group and the error bars represent the standard deviation of the mean (1σ).The repeatability and sensitivity (S) were calculated with the respective equations 1 and 2:

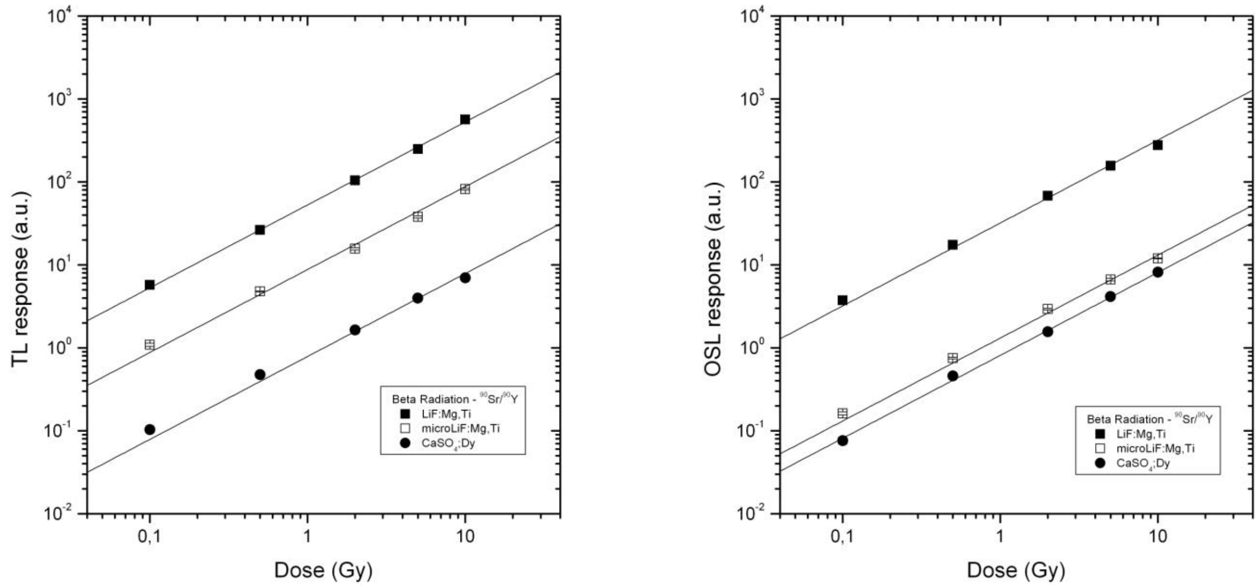
$$\text{Repeatability}\left(\%\right)=\frac{\sigma}{\sqrt{\text{n}}\cdot\overline{R}}\cdot 100 \qquad (1),$$

$$S(units.Gy^{-1})=\frac{\overline{R}}{D} \qquad (2),$$

where: "σ" is the standard deviation, "n" is the number of dosimeters, "$\overline{R}$" is the mean of the TL/OSL response of the dosimeters of each group and "D" is the absorbed dose.

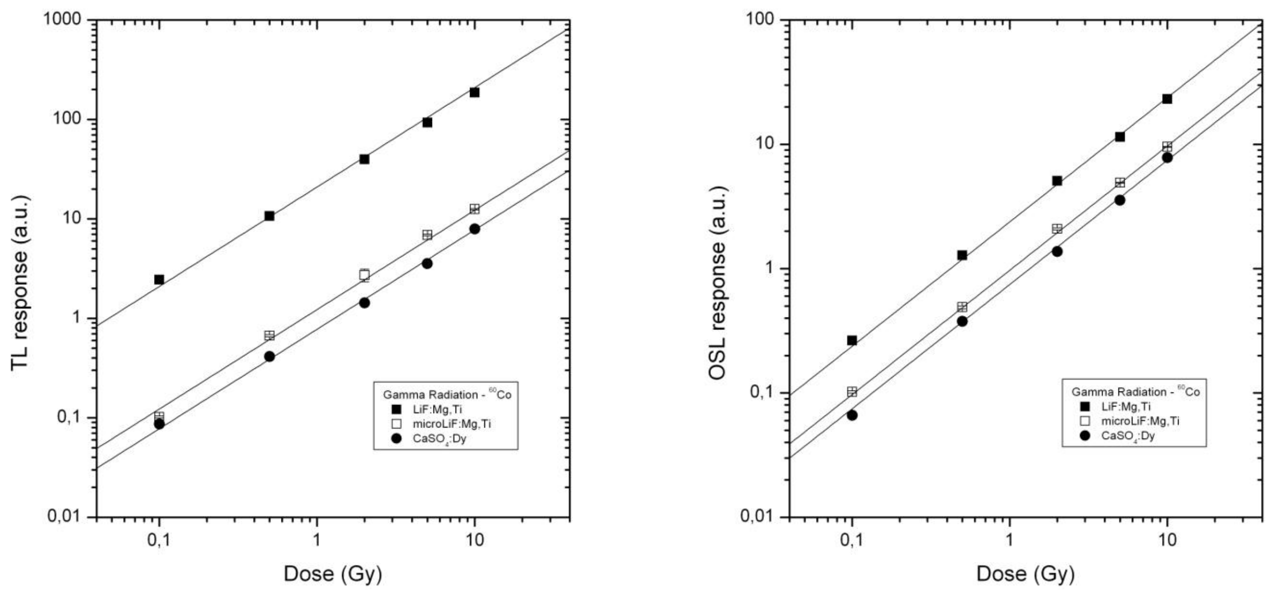
3. RESULTS

The TL and OSL dose-response curves of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to beta radiation with doses ranging from 0.1 up to 10 Gy are shown in the Figure 1a and 1b respectively. In the figures 2a and 2b are presented the TL and OSL dose-response curves of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to gamma radiation to the same dose range.



a) b)

Figure 1. $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dose-response curves a) TL and b) OSL to beta radiation.



a) b)

Figure 2. $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dose-response curves a) TL and b) OSL to gamma radiation.

The dose-response curves to beta and gamma radiation show a linear behavior in the absorbed dose range studied (0.1 to 10 Gy) for TL and OSL techniques and all dosimeters.

The Tables 1 and 2 present the sensitivity and the reproducibility of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to the different techniques to beta and gamma radiation respectively.

Table 1. Sensitivity and the repeatability of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to TL and OSL technique to beta radiation.

	$CaSO_4$:Dy		LiF:Mg,Ti		microLiF:Mg,Ti	
	TL	OSL	TL	OSL	TL	OSL
S (units.Gy^{-1})	0.083±0.002	0.082± 0.002	5.2 ± 0.13	3.4 ± 0.12	0.75±0.02	0.15 ± 0.03
Repeatability (%)	≤ ± 1.74	≤ ± 2.24	≤ ± 1.90	≤ ± 2.05	≤ ± 1.80	≤ ± 1.55

Table 2. Sensitivity and the repeatability of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to TL and OSL technique to gamma radiation.

	$CaSO_4$:Dy		LiF:Mg,Ti		microLiF:Mg,Ti	
	TL	OSL	TL	OSL	TL	OSL
S (units.Gy^{-1})	0.071 ± 0.001	0.069 ± 0.001	1.9 ± 0.1	0.26 ± 0.03	0.14±0.04	0.11 ± 0.01
Repeatability (%)	≤ ± 1.88	≤ ± 1.55	≤ ± 1.46	≤ ± 1.12	≤ ± 1.65	≤ ± 1.02

LiF:Mg,Ti dosimeters are more sensitive to TL and OSL techniques to beta and gamma radiation. To beta radiation these dosimeters presented sensibilities approximately 7 and 23 times higher than microLiF:Mg,Ti and 63 and 41 times higher than $CaSO_4$:Dy to TL and OSL techniques respectively. To gamma radiation, the sensitivities of LiF:Mg,Ti dosimeters are 14 and 2 times higher than microLiF:Mg,Ti and 27 and 4 times higher than $CaSO_4$:Dy to TL and OSL techniques respectively.

The repeatability of the dosimeters to beta and gamma radiation were smaller than ± 2% to both technique and dosimeters except to LiF:Mg,Ti and $CaSO_4$:Dy dosimeters to OSL technique.

4. CONCLUSIONS

In the dose range studied the dose-response curves of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti presents linear behavior to TL and OSL techniques to beta and gamma radiation. LiF:Mg,Ti dosimeters are more sensitive to the TL and OSL techniques for beta and gamma radiation. The repeatability of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti is in accordance with the literature (< ± 5%) to OSL and TL technique.

The obtained results indicate the viability of application of the $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters in TL and OSL beta and gamma radiation dosimetry and these dosimeters can be investigated to be applied in arc-IMRT (VMAT) dosimetry using both techniques.

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